

A Study on Prospective Green Chemistry Alternatives for Organic Synthesis in Order to Promote Sustainable Development

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ABSTRACT

This paper outlines the green initiatives aimed at promoting awareness of green chemistry as a viable substitute for conventional methods of organic synthesis. It offers novel insights, tools, and concepts for designing organic synthesis processes that are conducive to preserving environmental and public health, while promoting economic growth. Green chemistry alternatives are vital components in forestalling the risks posed by the hazardous environmental outcomes resulting from traditional synthesis that employ varying chemicals and solvents. This approach is pivotal in our mission to safeguard the planet from the adverse ecological effects of chemical-based processes.

Keywords: Green chemistry; Sustainable development; Green alternatives; Organic synthesis; Green solvents; Environmentally-friendly synthesis.

1. Introduction

The field of organic synthesis is experiencing a surge in popularity due to the emergence of green chemistry, a contemporary approach that has garnered recognition both locally and globally. The fundamental objective of green synthesis is to promote eco-friendly and sustainable progress. This is accomplished by maximizing output efficiency while minimizing the amount of waste generated during the production process. To achieve the objectives of green chemistry, a set of strategies must be employed, including waste avoidance, atom economy, the avoidance of auxiliary substances, the use of catalytic amounts of catalysts, the reduction of energy requirements, the use of renewable and biodegradable materials, and the promotion of energy efficiency.

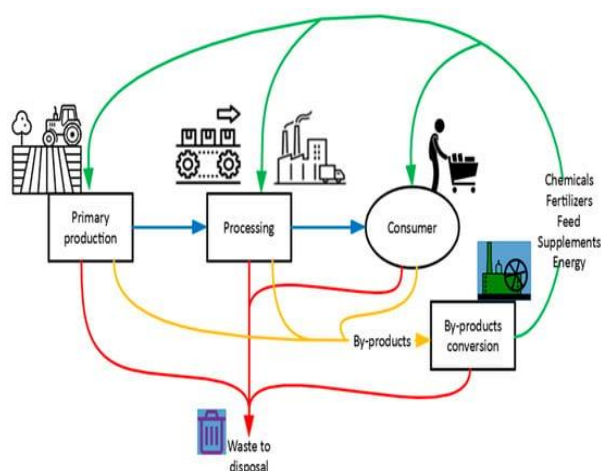


Figure 1. Schematic representation of a system that can integrate the circular economy and green chemistry in a strategic sustainability framework

In essence, green, and sustainable chemistry is the practice of designing, synthesizing, and applying chemical methods and processes that limit the production of harmful feedstock, by-products, solvents, and reagents. This

approach offers a viable alternative to the drawbacks associated with traditional, or gray, chemistry and is essential to securing a future characterized by environmentally friendly synthesis.

The Twelve Principles of Green Chemistry were established by Dr. Paul Anastas and Dr. John Warner in 1998 as a framework for designing chemical processes and products that are more sustainable and environmentally friendly. Here are the twelve principles of green chemistry expounded as follows:

(i) To minimize the generation of excess materials - When selecting chemical reactions for use, it is important to consider those that do not result in the production of byproducts that require disposal. For instance, the implementation of newer and safer pesticides like Spinosad would be ideal.

(ii) Utilize sustainable raw materials - The adoption of renewable starting materials, such as plants, over non-renewable options like fossil fuels, is a preferred approach in chemical processes. A prime instance of this is the employment of solid catalysis to hydrogenate carboxylic acids into aldehydes.

(iii) In order to optimize atom utilization - It is necessary to ensure that all reactant atoms are present in the final product, rather than being displaced by excessive by-products. This can be achieved by implementing solvent-less sample preparation techniques.

(iv) To develop a chemical synthesis process with reduced potential for harm - The objective is to identify chemical synthesis routes that are environmentally friendly and pose no health risks to humans. As an illustration, the production of adipic acid can be achieved via the oxidation of cyclohexene with the utilization of hydrogen peroxide.

(v) To utilize solvents with reduced hazards and incorporate reaction parameters that are safer - It is recommendable to use non-hazardous solvents and other materials when dealing with chemical reactions. The preference is towards safer solvents which can be easily obtained. A suitable example is observed in the comparison of fiber derivatization and derivatization in solution during sample preparation.

(vi) Utilize a catalytic quantity of catalyst - It is advisable to utilize a minimal amount of catalyst during chemical transformations instead of combining numerous chemicals. Examples of such practices include supercritical fluid extraction and synthesis in ionic liquids.

(vii) To optimize energy efficiency - It is recommended to decrease energy usage during synthesis by performing reactions at either ambient or reduced temperatures. A prime example of this is the Polymerization of Polyolefins, which serves as an eco-friendly alternative to PWC and can be achieved with significantly less energy expenditure.

(viii) To mitigate the risk of potential accidents - It is advisable to refrain from utilizing chemicals that have a high propensity to ignite, detonate, or emit hazardous substances. To illustrate, the production of decomposable polymers would be a suitable activity to avoid such chemicals.

(ix) To conduct real-time analysis aimed at preventing pollution - Ensure that chemical reactions are monitored and controlled to prevent environmental pollution. An example of this includes the production of surfactants requiring careful observation to maintain environmental standards.

(x) To circumvent the need for chemical derivatization - It is not recommended to attempt creating derivatives of harmful compounds as a means for a transformation, as this process entails utilizing more chemicals to convert them into the desired substance. For instance, the successful production of Efficient Au would require an alternative approach rather than using harmful compounds.

(xi) To develop chemicals and associated products that boast advanced safety capabilities - It is advisable to prioritize the production of chemicals and products that have minimal or zero toxic impact on the environment. As an illustration, in the process of methylation reactions, one can consider employing a more sustainable alternative such as Di-Me carbonate (DMC) rather than di-Me sulfate and Me-halides. DMC is well-known for its eco-friendliness and safety to the environment.

(xii) Opt for manufacturing non-biodegradable chemicals or products - Develop and create chemicals and products that have the ability to efficiently degrade after their intended use. The application of green chemistry principles across all aspects of the human life cycle, including human beings, can help safeguard nature and mitigate the risks associated with chemical exposure. By integrating these principles into chemical synthesis procedures, we can ensure greater protection for both the environment and human health.

2. Focuses on the application of classical chemistry principles in the process of organic synthesis

The synthesis of molecules is a critical aspect of scientific advancement, particularly in organic chemistry where classical routes are available for their creation. The art of organic synthesis lies in the construction of complex molecular structures using smaller, readily available building blocks. Synthetic chemists focus on both target-oriented synthesis, aimed at obtaining complex organic molecules, and method-oriented synthesis, which involves the development of new reagents, catalysts, reactions, and procedures.

Classical organic synthetic methods led to the discovery and synthesis of millions of organic compounds by the turn of the 20th century. These methods often involved the use of organic solvents, toxic reagents and catalysts, harsh reaction conditions, tedious work up processes, and long reaction times. Consequently, the need for safer and more sustainable alternatives to organic synthesis drove further research and development in this area.

Classical methods employed in organic synthesis within the field of chemistry pose significant risks to both human health and the surrounding environment. The organic solvents commonly used possess inherent properties such as their high volatility, flammability, and toxicity, which can cause severe health complications upon continuous inhalation and exposure at high concentrations. Annual disposal of waste solvents by industries also contributes to air and water pollution. Additionally, while catalysts serve to accelerate the reaction rate in classical organic synthesis, their use presents limitations such as insolubility, the high activation energy required, the need to use stoichiometric amounts, toxicity, high cost and expense, and limited selectivity.

3. The implementation of new green chemistry methodologies in organic synthesis

A fundamental challenge for chemists and other professionals is to generate novel products, processes and services that can deliver significant societal, economic, and environmental benefits in the field of organic synthesis. Overcoming these obstacles necessitates adopting a fresh approach that seeks to minimize the utilization of

materials and energy in chemical processes and products, reduce or eliminate the release of hazardous substances into the environment, maximize the use of renewable resources, and enhance the durability and recyclability of products. Within the realm of organic synthesis, chemists are required to address the challenges of identifying and developing innovative synthetic pathways utilizing green chemistry techniques.

- Eco-friendly solvents.
- The implementation of green catalytic mechanisms in the field of organic synthesis.
- "Synthesis of dry media materials".
- Organic synthesis techniques that do not rely on catalysts.
- Optimization of energy consumption during synthesis.

(1) Use of Eco-friendly solvents

Green solvents are recognized for their favorable environmental properties, including low toxicity and poor miscibility in water, as well as easy biodegradability under natural conditions. They also possess advantageous features such as high boiling points, which prevent rapid evaporation, minimal offensive odor, and reduced health hazards to personnel.

The chemist has recently incorporated Water, Ionic Liquids, Supercritical fluids, and Polyethylene glycols as green solvents, utilizing the principles of green chemistry. By applying these green solvents, significant advancements have been made in the development of eco-friendly reaction processes for organic synthesis.

(2) The implementation of green catalytic mechanisms in the field of organic synthesis

Catalysis plays a crucial role in the realm of Green Chemistry. By designing and employing novel catalysts and catalytic systems, we can achieve the dual objectives of environmental preservation and economic gain. One of the most significant advantages of catalysis in Green Chemistry is its ability to lower energy requirements, promote catalytic activity rather than stoichiometry, improve selectivity, reduce the use of processing and separation agents, and allow for the use of less hazardous materials.

Catalysis is bifurcated into two branches: homogenous catalysis, where the catalyst operates in the same phase as the reaction mixture (typically in the liquid phase), and heterogeneous catalysis, where the catalyst functions in a different phase (usually solid/liquid, solid/gas, or liquid/gas). Ideal homogenous catalysts can be particularly useful because their active sites are spatially well-separated, much like enzymes during catalysis.

Heterogeneous catalysis is a key technique in Green Chemistry which aims to achieve efficient phase separation of the catalyst and product, as well as bifunctional phenomena involving reactant activation between the active and support phases. This approach minimizes the need for costly separation processes such as extraction or distillation. Furthermore, environmentally friendly catalysts, such as clays and zeolites, can potentially replace hazardous catalysts currently in use. Considering this, the selection of catalysts assumes critical importance in the modern day where environmental consciousness is paramount. To meet the standards of Green Chemistry, highly corrosive, toxic, and polluting acid catalysts must be substituted with eco-friendly and renewable catalysts, particularly ionic liquids.

(3) Synthesis of dry media materials

A chemical reaction system without the presence of a solvent is commonly referred to as a dry media reaction, solid-state reaction, or solventless reaction. This type of reaction can be carried out by solely utilizing reactants or incorporating them into catalytic substances such as clays, zeolites, silica, alumina, and others.

Various methods such as thermal processing, UV irradiation, microwave and ultrasound can be employed to initiate the reaction. Opting for solvent-free reactions can effectively minimize pollution and promote economic feasibility due to several factors, such as uncomplicated experimental procedures, efficient work-up methods, and timesaving. These advantages become especially significant when applied to industrial production. Consequently, it is worth noting that solid state reactions typically produce different products than those obtained via solution phase reactions. This can be attributed to the particular spatial orientation or arrangement of the reacting molecules within the crystalline phase. These observations hold true not only for single compound crystals, but also for co-crystallized solids containing two or more reactant molecules.

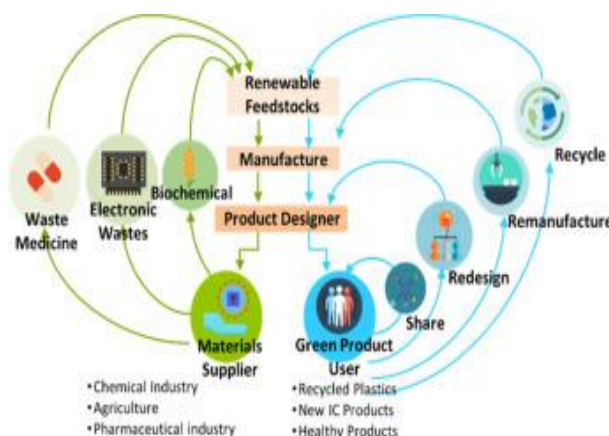


Figure 2. Implementation of green chemistry

(4) Organic synthesis techniques that do not rely on catalysts

Within the realm of organic synthesis, the word "catalyst" refers to a substance or reagent that serves to increase the speed or efficiency of a chemical reaction - a process known as catalysis. Though a catalyst may engage in multiple chemical transformations during catalysis, its effect may fluctuate depending on the presence of other substances that either stifle or intensify its catalytic activity. Of note, unlike other reagents involved in the chemical reaction, a catalyst is not used up or exhausted.

The utilization of a catalyst has the potential to modify the rate or selectivity of a chemical reaction, and in some cases, it can facilitate the reaction to occur at lower temperatures. Additionally, the introduction of a catalyst can allow for the creation of several bonds in a single sequence without requiring alterations to the reaction conditions or separate isolation of intermediates and reagents. This can result in a reduction of waste, cost, and labor. However, it is important to note that certain limitations and drawbacks have been identified in relation to the use of catalysts, such as their insolubility, which can lead to longer reaction times due to increased activation energy. In some cases, stoichiometric amounts of the catalyst may also be necessary, or the catalyst may be toxic, costly, and offer limited selectivity, which can ultimately hinder the efficiency of the process.

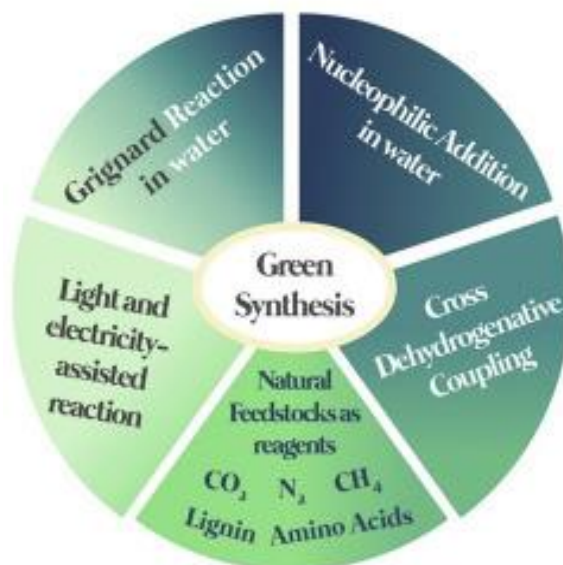


Figure 3. Organic synthesis and techniques

Traditionally, classic organic reactions have relied on the use of catalysts (homogeneous and/or heterogeneous) or reagents combined with organic solvents (which can range from lethal and poisonous to environmentally benign) to achieve desired products. Despite the difficulty of avoiding their use, eliminating the use of catalysts and hazardous solvents in organic reactions is crucial. Therefore, the catalyst-free synthesis of various organic compounds is the optimal eco-friendly alternative for chemists involved in organic synthesis.

4. Conclusion

To address the impact of globalization and technology, it is crucial to explore new approaches that prioritize environmentally friendly methods in organic synthesis. Green chemistry principles, such as solvent-free organic reactions, catalyst-free organic reactions, and the use of water and ionic liquids as green solvents, offer promising alternatives. A thorough examination of the literature highlights a rising requirement for synthetic methodologies that prioritize societal and human health benefits. These perspectives underscore the importance of developing greener alternatives to organic synthesis.

Declarations

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Competing Interests Statement

The authors have declared no competing interests.

Consent for Publication

The authors declare that they consented to the publication of this study.

Authors' Contributions

All the authors equally participated in research and drafting of the manuscript.

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